GOVERNMENT OF INDIA

CENTRAL STANDING COMMITTEE

FOR

COORDINATION OF POWER & TELECOMMUNICATION SYSTEMS

ENGINEERING REPORTS

VOLUME I

PRINTED BY THE MANAGER GOVERNMENT OF INDIA PRESS, SIMLA AND
PUBLISHED BY THE MANAGER OF PUBLICATIONS, CIVIL LINES, DELHI-8

Price : Rs. 3/6/- or 5sh. 6d.

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ERRATA

Contents page, Engineering Report No. 1—Pages ' 1—19 ' should be ' 1—20 '.

Page 2, 2nd line from bottom—' screenin ' should be ' screening '.

Page 3, 5. 1., 3rd line—' were ' should be ' was '.

Page 5, 6. 2., last line—' p ' should be ' ρ '.

Page 6, Table II, Col. 4—' Earth resistance ' should be ' Electrode resistance '.

Page 7, 7. 1. 4., 4th line—' shiedling ' should be ' shielding '.

Page 8, 8. 1. 2., 1st line—' Fig. 14 ' should be ' Fig. 8 '.

Page 9, 9. 1. 1., 1st line—' tests ' should be ' test '.

Page 13, Appendix I, under CDP4, 3rd line—' 205 omhs ' should be ' 205 ohms '.

Page 15, table under Exp. 4, 2nd line—' amprees ' should be ' amperes '.

Page 18, 1st line—(e) should be (c).

Page 19, Appendix III, 5th line—' syestem ' should be ' System '.

Page 19, Formula (B)—' p ' should be ' ρ '.

Page 19, Under formula (B), 4th line—' meter-ohms ' should be ' metre-ohms '.

Page 22, 9th line ' is the specific resistivity ' should be ' ρ is the specific resistivity '.

Page 22, 3. 2., 6th line—' are earrived ' should be ' are arrived '.

Page 22, 11th line from bottom—' Milonelts ' should be ' Millstone '.

Page 24, 4. 3. 2., 5th line—' forrous sulphate ' should be ' ferrous sulphate '.

Page 24, 4. 4. 1., 3rd line—' 15°C ' should be ' —15°C '.

Page 25, 9th line—' meter-ohms ' should be ' metre-ohms '.

Page 26, 5. 3. 3., last line—' ox de ' should be ' oxide '.

Page 28, 10th line—' ρ^1/ρ_a ' should be ' ρ_1/ρ_a '.

Page 30, Bibliography, No. 7—' M/T 30 ' should be ' M/T 31 '.

Page 31, 1. 1., 3rd line—' telephone lines ' should be ' telephone line '.

Page 31, 1. 1., 7th line—' telephone line ' should be ' telephone lines '.

Page 32, 2. 3., 9th line—' externa ' should be ' external '.

Page 32, foot note, 1st formula for gmr— $\left[\cdots\cdots\right]\frac{1}{n^2}$ should be $\left[\cdots\cdots\right]^{1/n^2}$.

Page 32, foot note, 2nd formula for gmr—should be $\left[(gmr)^n \, d^2_{12} \, d^2_{13} \cdots\cdots \, d^2_{n-1n}\right]^{1/n^2}$.

Page 33, 2. 6., 3rd line—' susbcripts ' should be ' subscripts '.

Page 33, foot note, 2nd line—' d d_{1b} ' should be ' d_{1a}, d_{1b} '

Page 34, formula (9c)—should be $I_7 = \left[\frac{-3Z_{17}}{Z_{77}+Z_{78}}.I_9\right]$.

Page 35, 3. 3., 1st line—' resistances ' should be ' resistance '.

Page 36, 4. 2., lines 4 & 5—' Madhurai ' should be ' Madurai '.

Page 36, last line—' ng ' should be ' ing '.

Page 37, 5. 2., formulae—' V ' should be ' V_1 '.

Page 39, 6. 1., 18th line—' =V+drop ' should be ' E=V+drop '.

Page 39, in equation (27)—' I ' should be ' 1 '.

Page 41, Table III, Col. 4—' immpedance ' should be ' impedance '.

Page 41, Table III, Col. 7, 6th line from bottom—(129°-6") should be (129°-6').

Page 41, Table III, Col. 8, 2nd line—(114'-3') should be (114°-3').

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Page 43, 7. 2., 2nd line—' Coimbatore and ' should be ' Coimbatore end '.

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FOREWORD

The problem of electromagnetic and electrostatic induction between high voltage power lines and telecommunication lines has lately been engaging the attention of engineers in India. The increased developmental activity in the postwar years of both power and telephone services led frequently to situations of conflict ; and it was soon realised that special efforts should be made to understand the nature of this interference problem and to devise satisfactory means of overcoming the trouble.

Arising from the recommendation of the All-India Power Engineers' Conference in February 1949, at which this problem was discussed, the Government of India set up the Central Standing Committee for Coordination of Power and Telecommunication Systems. This Committee consisting of representatives of both power and telecommunication interests in India, is required to make a detailed study of all aspects of the problem of interference between power and communication systems, carry out scientific investigations and experiments wherever necessary, make a comparative study of the practices adopted in foreign countries to deal with this problem and to recommend suitable co-ordination methods to be adopted by engineers in India.

In regard to scientific investigations on the problem of interference between power and telecommunication lines, the Committee's work can be broadly divided into the following three categories :

(1) *Low Frequency Induction* : Studies under this would include the development of means for predetermining low frequency voltages and currents in inductive exposures and consideration of measures for reducing the low frequency inductive influence of power systems and the low frequency inductive susceptiveness of communication systems.

(2) *Noise Frequency Induction* : Studies under this category would include the determination of the optimum noise levels for ensuring satisfactory telephone service, investigation of the sources of wave-shape distortion, and unbalance in power systems, study of coupling factors involved in noise frequency induction and the development of remedial measures.

(3) *Structural Co-ordination and Protection against physical contacts* : Examination of design and construction features in the case of power and telecommunication lines carried on the same supports or power telecommunication line crossings etc. would come under this study.

The Committee has so far made a start with the study of low frequency induction only. It is hoped that in due course it will be able to undertake further studies on the other subjects also.

The three reports included in this volume are first of a series of reports which the Committee hopes to issue from time to time.

V. R. RAGHAVAN
and
B. S. RAU,
Joint Secretaries, Central Standing Committee for Coordination of Power & Telecommunication Systems.

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Engineering Report No. 1

ENGINEERING REPORT NO. 1

LOW FREQUENCY INDUCTIVE INTERFERENCE BETWEEN POWER AND TELECOMMUNICATION LINES—FIELD TESTS CONDUCTED AT AMRITSAR AND BOMBAY.

1. *Introduction.*—This report describes the experiments carried out in the year 1949, in connection with inductive interference from earth currents arising from H.T. Power transmission lines on neighbouring telephone lines. The object of the tests was to gauge and understand by direct experimentation, the actual extent of low frequency electromagnetic induction between power lines and proximate and parallel telephone lines and to determine by comparison with theoretical computation the degree of agreement between calculated values and observed results under different conditions. In the context of the rapid development of large electrical power net-works in India, which is likely to result in increasingly frequent interference situations in future, this subject assumes wide significance. It is hoped that the experience gained by such investigations would be of value in the practical solution of the conflicting situations likely to be encountered by Power and Communication engineers.

2. *Scope of investigation.*—The report describes the results of experiments carried out at Amritsar on the 132 kV lines of the Jogindernagar hydroelectric system in August 1949 and at Kalyan and Mulund on the 22 kV lines of the Tata Power Co. Ltd. in November 1949.

3.1. *Amritsar Tests.*—

3.1.1. In the Amritsar tests, the interference situation was between the 132 kV power transmission lines in the Amritsar-Jullundur section of the Punjab hydroelectric network and the neighbouring Delhi-Amritsar carrier telephone lines. The parallelism was in the section between Amritsar and Jullundur, a distance of about 50 miles. The average spacing between the disturbing (power) and the disturbed (telecommunication) circuits was about 1270 feet. The sketches shown in Figs. 1, 2 & 3 indicate the geographical as well as the electrical layouts of the relevant portions of the Punjab power system and also full technical particulars of the power lines under test.

3.1.2. Tests were conducted to determine the mutual coupling between the power and communication lines, when these are operated as earth return circuits. Besides, experiments were also carried out to determine the extent of shielding against electromagnetic induction between the circuits, which would result by the use of earthed conductors on (*i*) the power lines and (*ii*) the telephone lines. A known current was circulated between the conductors on the power line and the earth return and the induced voltage on the communication wires to earth was measured by a suitable voltmeter. The tests were repeated using one or more conductors of the power lines and of the telephone lines as shielding conductors by earthing them at the terminals. Full details of the tests are described later in this report and in Appendix I.

3.1.3. In the parallelism situation between Amritsar and Jullundur there is, as far as one can see, no extraneous source which may be expected to affect the electromagnetic induction between the power and communication circuits. There is no irrigation canal, pipe line or other electrically conducting earthed circuits in the neighbourhood to be taken account of. The railway track running parallel to the lines, not being bonded, is not expected to contribute to the shielding between the circuits. The effect of the earthed telegraph wires along the railway line will be purely local and can therefore be ignored in the case under consideration. In other words, this section should be considered ideal for the purpose of carrying out the electromagnetic induction tests.

3.2. *Bombay Tests.*—

3.2.1. In the Bombay tests, the interference situation was between the Kalyan-Vikhroli 22 kV lines of the Tata Power Co., and the trunk telephone circuits running along the electrified railway tracks between Kalyan and Bombay. Figures 4, 5 and 6 indicate the geographical and the electrical layouts of the lines under test, as well as the full technical particulars of the power circuit.

3.2.2. The situation in Bombay was complicated by the presence of the electrified railway tracks which run parallel to and between the power and communication lines under tests. On the one hand, the D.C. harmonics of the track-currents induce extraneous voltages on the communication lines and on the other, the tracks, being a well-bonded earthed circuit, exert a substantial screening effect to the mutual coupling between the power and communication lines. In fact, one of the reasons for choosing Bombay for conducting these experiments was to make an attempt at the indirect determination of the actual shielding effect exerted by the railway tracks.

3.2.3. The close parallelism was in the section between Mulund and Vikhroli, a distance of about 5 miles, the average spacing being 950 feet. The 22 kV line was solidly earthed at Vikhroli (all the three conductors were bunched together) and a low tension supply connected between the conductors and earth at the Mulund City substation. The induced voltage between the telephone wires and the earth was measured successively in the following sections of the Bombay-Kalyan trunk telephone wires :—

(*i*) Mulund—Vikhroli.

(*ii*) Mulund—Bombay.

(*iii*) Kalyan—Bombay.

3.2.4. Besides the above experiments where currents at low voltage were used, a full scale short circuit test was also conducted. The 22 kV line from Kalyan to Vikhroli was closed at Kalyan on a dead earth fault at Vikhroli and oscillographic records taken of the earth fault current as well as the induced voltage on the Kalyan-Bombay trunk telephone lines. The result of this test is shown in figures 9 and 10.

3.2.5. Opportunity was also taken to observe the extraneous induction on the telephone lines arising from the currents flowing in the electric traction system. Observations on a cathode ray oscillograph showed that the wave form of this extraneous voltage was complex with a pronounced eighth harmonic.

4.1. *General.* During the normal operating conditions of a power transmission line, the amount of electromagnetic induction in a neighbouring and parallel telecommunication line at the supply frequency of 50 cycles per second is negligible, owing to the almost complete absence of earth return currents. However, during abnormal conditions such as when an earth fault occurs on any one phase of the power line, large fault currents flow in the power conductors and return through the earth. Under such conditions, the power line and the neighbouring telephone line form two parallel earth return circuits with a high degree of mutual coupling. The mutual coupling between two earth return circuits can be calculated with the aid of the formulae developed by Carson and Pollaczek or from coupling curves derived from these formulae, provided the resistivity of the earth in the area and other relevant particulars such as separation between the circuits, height of the conductors above the ground etc. are known. With this knowledge of the mutual coupling between two circuits, the voltage induced in one circuit as a result of given current in the other, can be calculated.

4.2.1. Two uncertain factors, however enter into the theoretical computation of the induced voltage. These are (*i*) the earth resistivity of the area, and (*ii*) the screenin effect of earthed conductors etc. in the neighbourhood.

4.2.2. The earth resistivity in an area can be measured in several ways, but the results of measurements by different methods do not tally closely. The resistivity of the soil often varies quite considerably in two adjacent locations or even in the same location at different times. The earth resistivity in a particular area is an extremely complex function of the geological formation of the earth's crust and a discussion on the methods for accurate determination of the earth resistivity is beyond the scope of this paper. Fortunately, as far as the question of electromagnetic induction between two earth return circuits is concerned, even an approximate value of earth resistivity is good enough to compute to a reasonable degree of accuracy, the induced voltage by the Carson-Pollaczek curves. The measurements of earth resistivity taken under the tests described in this paper may therefore be assumed as reliable for the purpose envisaged. Actually, it is noticed that the earth resistivity obtained by the four electrode method using the Evershed and Vignoles Megger Earth Tester (*vide* para 6.1.) yielded results which agree closely with theoretical calculations.

4.2.3.1. The screening effect of earthed conductors such as the ground wires on power lines can be calculated theoretically, although it is a tedious process. In the situations under test, calculations were made of the shielding factors due to the steel ground wires used on the power lines. In the case of the Amritsar-Jullundur line, calculations were also made of the shielding due to earthing of one or two of the power wires. As shown later in the report, there is remarkable degree of agreement between the observed and calculated values of the shield factors.

4.2.3.2. The screening effect due to such earth current paths such as irrigation canals, water pipes and bonded railway tracks does not, however lend itself to simple mathematical analysis. The only means therefore, by which the screening factor due to such circuits can be ascertained is to calculate the mutual coupling between the power and telecommunication circuits assuming no screening and to compare this with the mutual coupling as obtained by an actual induction test.

4.3. This report has been divided into three parts :—

Part I deals with the determination of Earth Resistivity.

Part II deals with the determination of the mutual coupling between two earth return circuits.

Part III deals with the determination of the screening factor.

Appendix I gives full details of the observations etc. recorded during the tests at Amritsar.

Appendix II gives full details of the observations etc. recorded during the tests at Bombay.

Appendix III gives the general methods adopted for calculating the shield factors.

Acknowledgments

5.1. The tests at Amritsar were carried out with the assistance of the Electricity Branch of the Punjab Government and of the Indian P. & T. Department. The success of the tests were in a large measure due to the cooperation of Mr. H. R. Bhatia, Projects Engineer, Electricity Branch, Punjab Government, who made all the arrangements and was present during the tests. Our thanks are due to Mr. G.S. Gyani and Mr. H.S. Uppal, Executive Engineers and to the local staff of the Electricity Branch at Amritsar and at Jullundur. Thanks are also due to Mr. Mukundan, Divisional Engineer, Telegraphs, Jullundur and Mr. Puran Singh, Sub Divisional Officer, Telegraphs, Amritsar for making necessary arrangements on the telecommunications side. Grateful acknowledgment is also made to Dr. K.S. Krishnan, F.R.S., Director, National Physical Laboratory, Delhi, who had kindly arranged for loan of several measuring instruments etc. for use during the tests at Amritsar.

5.2. In regard to the Bombay tests, the elaborate arrangements made by Mr. Zubair, Chief Engineer, The Tata Power Company Ltd., are gratefully acknowledged. Thanks are due for the assistance rendered in carrying out the experiments to Mr. Bapat, Superintendent, Transmission Lines, Mr. Bangale, Superintendent, Tests and other staff of the Tata Power Co. Ltd., and Mr. Raja, Sub-Divisional Officer, Telegraphs, Bombay.

5.3. Mr. A.S. Muthuswamy of the P. & T. Development Branch and Mr. T.V. Thadhani of Central Electricity Commission also rendered valuable assistance.

PART I

Determination of Earth Resistivity

6.1. *Use of "Evershed Vignoles Megger Earth Tester"--Four electrode method.*—Four spikes are driven into the ground at equal intervals "a" cms. (Fig. 7). The depth insertion of the spikes in the ground should not exceed one twentieth of "a". The two outer spikes are connected to the instrument terminals C_1 and C_2 and the two inner spikes to the terminals P_1 and P_2. The megger handle is rotated steadily and the final steady reading "R" ohms shown on the dial is recorded. If the homogeneity of the soil is assumed, it can be shown that the earth resistivity in ohms/cm ^{3} is connected with R by the relationship.

$$\rho = 2\pi aR$$

6.1.1. Most observations were taken with spikes intervals of 50 feet. When the interval was increased to 75 feet and 100 feet, it was found that the values of the earth resistivity as calculated by the above formula increased. (*Vide* Table I.)

6.1.2. Errors from polarisation effects etc. are avoided in this method of measuring resistivity, as the Megger Earth Tester operates on intermittent current.

TABLE I

Locality and date of test	Separation "a" in feet.	Megger reading R in ohms	Calculated earth resistivity in ohms/ cm^3
Amritsar, 6th August 1949	50	0·3	2871
Jullundur, 6th August 1949	50	0·4	3828
Sion, 25th November 1949	50	0·11	1053
Do.	50	0·02	191
Mulund, 26th November 1949	50	0·15	1436
Do.	50	0·18	1722
Do.	75	0·14	2010
Do.	75	0·13	1866
Bhandup, 26th November 1949	50	0·22	2105
Do.	50	0·24	2297
Do.	100	0·24	4594
Do.	100	0·20	3828
Vikhroli (Uneven land), 26th November 1949	50	0·19	1818
Do.	50	0·19	1818
Do.	100	0·27	5168
Do.	100	0·27	5168

6.1.3. The increase in the resistivity due to increased spacing of spikes appears to be due to different strata in the earth's depth having different resistivities. Radley and Whitehead have stated (JIEE Vol. 74, March 1934, page 218) that it is possible from a series of tests at different electrode spacings to deduce resistivities of an upper and a lower layer, but that greater complexity of the earth's crust, makes accurate deduction almost impossible. They have further stated that the four electrode test gives greater geophysical detail than is necessary for interference calculations and that great care should be taken in deducing the appropriate mean earth resistivity. This matter is dealt with in greater detail in Engineering Report 2.

6.1.4. From an inspection of Table I above, it would appear that the mean earth resistivity of a top layer of the ground in the Bombay area is of the order of 1,500 ohms/cm^3. There is probably also a deeper layer below this having a much higher resistivity of the order of about 5,000 ohms/cm^3. For the Amritsar-Jullundur area, 3,000 ohms/cm ^{3} may be taken as a representative resistivity for the purpose of calculating mutual coupling between earth return circuits.

6.2. *Use of "Evershed-Vignoles Megger Earth Tester"—Three electrode method.*—This method is based on a formula connecting the earth resistivity with the electrode resistance of an earthing terminal such as a rod or pipe driven vertically into the ground :

$$R = \rho \log_e \left(\frac{4l}{d}\right) / 2\pi l$$

Where R is the electrode resistance in ohms

l is the depth in cms to which the pipe or rod is driven underground.

d is the diameter in cms of the pipe or rod.

p is the earth resistivity in ohms/cm^3.

6.2.1. The measurements made with the Megger Earth Tester were utilised for evaluating the earth resistivity by this method also. The cross section of the spikes used in the tests in the Bombay area was not circular, but in the form of a six pointed star. Moreover these spikes had a long pointed end. However, for the purposes of calculation with the above formula, an average diameter of 2 cms. was adopted.

6.2.2. In making measurements under this method, the terminals P_1 and C_1 of the instrument were connected together and connected to the spike (electrode) under test. (*See* Fig. 7). Terminals P_2 and C_2 are connected to two auxiliary spikes driven at distances sufficiently large as not to cause mutual interference between the fields of the different electrodes. The megger reads the electrode resistance directly.

6.2.3. Table II gives the results obtained by the three electrode method which may be compared with those obtained by the four electrode method (*vide* Table I). It is observed that there is considerable variation between the results obtained by the two methods. The probable reasons for this discrepancy between the three electrode and four electrode methods of measurement are dealt with in the Engineering Report 2.

TABLE II

Locality and date of test	Mean Diameter of rod in cms 'd'	Depth of rod in inches	Earth resistance R in ohms	Calculated earth resistivity in ohms/ cm^3
Amritsar, 6th August 1949	4·8	24	7	683
	4·8	12	5	297
Jullundur, 6th August 1949	2·56	17	60	3880
	2·56	27	130	11850
Sion, 25th November 1949	2	13	15·8	783
	2	14	18·0	941
Mulund, 26th November 1949	2	10·5	55·0	2320
	2	9·5	125·0	4900
Do.	2	10·0	225·0	10350
Bhandup, 26th November 1949	2	7·0	212·0	6700
	2	9·0	210·0	7910
Do.	2	7·0	288·0	9010
Do.	2	8·0	98·0	3390
Vikhroli, 26th November 1949	2	9·0	90·0	3390
	2	12·0	74·0	3450
Do.	2	9·0	98·0	3690
Do.	2	13·0	138·0	6840

PART II

Determination of the Mutual Coupling between Power and Telecommunication Lines

7.1. *Amritsar Tests*—

7.1.1. The mutual impedance between the 132 kV line from Amritsar to Jullundur and the carrier telephone pair CDP 3 in the same section was calculated theoretically. This was done by plotting the routes of the disturbing and the disturbed circuits on a large scale map. Ordinates were drawn on the map at right angles to the power line route at reasonably close intervals to take into account the variations along the route in the separating distances between the two circuits. The mutual coupling between the circuits was determined for each small interval, where the mean spacing could be assumed to be uniform for all practical purposes, with the help of the Carson-Pollaczek curves. The total coupling for the whole section was determined by summating the couplings of the individual segments. The results of the calculations on the Amritsar-Jullundur Section yielded a mutual impedance of 3·72 ohms, in other words, for every ampere of current, circulating in the earth return circuit of the power lines, the longitudinal voltage to earth on the telephone wires would be 3·72 volts, assuming complete absence of all shielding influences.

7.1.2. The mutual impedance calculated above was verified experimentally. The three conductors of the power line as well as the two limbs A and B of the telephone line CDP 3 under test were solidly earthed at Jullundur end. Predetermined currents (obtained from the station transformer at Amritsar) were circulated between the power conductors and the earth and the voltage* to earth on the telephone wires measured at Amritsar. (Please see schematic arrangement of the connections shown in Figures 11 to 15 and the tables in Appendix I).

7.1.3. No noticeable difference was observed in the induced voltage, whether one conductor or all three conductors in parallel were used for circulating the disturbing current. There was, however, an inexplicable discrepancy in the values of the induced voltage observed on the two limbs A and B of the carrier telephone line, CDP 3, although the wires were tested before and after the experiments, for conduction, insulation and extraneous earths. As it was observed that the readings on the limb A were not as consistent as those on limb B, only the latter readings were accepted for drawing conclusions from these tests.

7.1.4. The experimental value of the mutual impedance was 3·5 volts/amp. The slight difference between this figure and the value of 3·72 derived by calculation (para 7·1·1) is due to the small screening influence exerted by the permanent steel ground wire installed on the power line. This shiedling has been calculated to be about 5% (*Vide* part III, Table IV) and when this is allowed for, the calculated and observed values of the coupling agree very closely.

7·2. *Paths of the ground-return currents in the earth.*

7.2.1. During the course of these tests, a very interesting point about the distribution of ground currents in the earth was verified. A reference to the geographical layout of the 132 kV transmission lines of the Joginder nagar power system (Fig. 1) would show that the lines beyond Amritsar towards Jullundur "loop back", so to say, towards the generating station. It might be expected that in the event of a line to earth fault on the Amritsar-Jullundur section of the 132 kV lines, fault currents would pass through the overhead conductors from Jogindernagar to the point of fault in the forward direction and return by the direct path in the earth between the point of fault and the step-up transformer neutral at Jogindernagar. Thus although there is a high degree of mutual coupling between the earth return circuits of the 132 kV lines and the telephone lines in the Amritsar-Jullundur section (3·72 volts per ampere), it might be imagined that since the path of the ground currents in the event of an earth fault on the power line would not be parallel to the route of the lines, there would be little electromagnetic induction on the telephone lines.

7.2.2. A test was conducted to verify the above assumption. In the section between Jogindernagar and Amritsar supply was changed over to No. 1,—132 kV line and the No. 2 line was isolated. The No. 2 line (deadened) was made through at the intermediate substations Kangra, Pathankot and Dhariwal, and connections made as shown in Fig. 15. 230 V single phase supply was injected between the conductors and the earth at Jogindernagar end, causing a current to flow from Jogindernagar to Jullundur by the overhead conductors and return *via* earth from Jullundur to Jogindernagar and measurement was made of the longitudinal induced voltage on telephone lines. Contrary to the expectations, it was found that the mutual impedance between the circuits had not been reduced and was of the same order as in the earlier experiment.

7.2.3. The conclusion that arises from this test is that the mutual coupling between two earth-return circuits is independent of the position or location of the generating station or

* Since electromagnetic type measuring instruments were used, the observations do not indicate strictly the open circuit induced e.m.f. on the telephone lines. In Engineering Report No. 3, a method for allowing for drop in voltage in the self impedance of the line and the resistance in the instruments has been worked out.

the substation to which the ground currents of the disturbing circuit ultimately return. *In other words, the ground currents do not take the shortest path between the source of supply and the fault, but follow the route of the overhead line from the fault point to the source.*

7.2.4. This result appears at first sight to be surprising ; but a little consideration would show that this is just what is to be expected. The distribution of the ground currents is controlled by two factors, *viz.* the resistance and the reactance drops. The former occurs mainly in the vicinity of the earth electrodes or the faulted points ; but beyond a short distance from the electrodes on the faulted points, the density of the current is so small that no substantial additions to the voltage drop arise from resistance to current flow. On the other hand, the configuration of the earth return circuit determines its reactance. The currents will take that path in which the reactance or in other words the magnetic energy associated with the circuit is minimum. To satisfy this condition the loop formed by the forward and the return paths of the current should be as small as possible, *i.e.* the ground currents should follow the overhead wires throughout the route.

8.1. *Bombay Tests—*

8.1.1. As stated earlier, the exposure section in the Bombay experiments was between Mulund and Vikhroli. The three conductors of the 22 kV line were solidly earthed at Vikhroli. Availing of the 230 V supply at the Mulund City Substation, current was circulated in the earth return circuit and the induced voltage on the parallel telecommunication wires (Bombay-Kalyan trunk lines) measured. (*Vide* detailed connections shown in Fig. 8 and Appendix II). The values of the induced voltage per unit current were the same on either limb of the telephone pair, unlike the discrepancy noticed in the tests at Amritsar. It was also noticed that the mutual coupling was the same whether the disturbing current was circulated through one conductor or all the three conductors in parallel.

8.1.2. Fig. 14 shows the observed values of the induced voltage plotted against the inducing current. The points lie on a straight line, which, however, cuts the 'Y' axis at a value of 0·2 volts, indicating an extraneous induced e.m.f. of the order of 0·2 volts. This extraneous induction, however, was actually observed to be of the order of 4 to 8 volts, when the earth return current was switched off. The explanation for this appears to be that the voltage arising from induction from power line happened to be in approximate phase quadrature with the extraneous voltage so that when the two voltages were superposed, the resultant value was not appreciably different from that of the major component. It was also observed that the induced voltage on the telephone wires was about 72° behind the inducing current on the power line which indicates that the mutual coupling included resistance component and was in the nature of a mutual impedance rather than a pure reactance.

8.1.3. The measured value of the mutual impedance cannot be directly compared with the theoretically calculated value owing to the substantial screening effect of the bonded railway track and of the ground wire on the power line. An attempt has been made later in this report to evaluate approximately the shield factor due to the tracks.

8.1.4. The induction tests were repeated and measurements were made of induced voltages on the telephone wires in the Bombay-Mulund, and Bombay-Kalyan sections—*i.e.* in sections of the telephone line extending beyond the exposure. Unfortunately, however, the observations are not consistent and do not therefore appear reliable. This is perhaps due to the uncertain effects of extraneous induction from different sections of the electrified rail track and it is considered unsafe to draw any conclusions from these observations.

8.2. In continuation of the induction tests described above in which currents at low voltage were circulated, a full voltage short-circuit test was also carried out on the Kalyan-Thana-Mulund-Vikhroli 22 kV line with an artificial earth fault at Vikhroli end. Oscillographic records of the earth fault current as well as the voltage to earth induced on the Kalyan-Bombay trunk telephone wires were obtained. The short circuit tests were carried out

(1) with high speed relay in operation, when the switch tripped in 12·5 cycles, and (2) with the high speed relay cut out of operation, when the switch tripped in 30·5 cycles. The oscillographic records are reproduced in Figs. 9 and 10 and the values of current and induced voltage as shown in the oscillograms agree closely with the experiments carried out at low voltage.

8.3. The stray voltages induced on the telephone lines due to the currents on the railway track etc., could be observed on the oscillograph. This voltage had a complex waveform with a pronounced harmonic at 400 cycles per second. The mean magnitude of the voltage was about 7 volts. Due to non-availability of photographic films, it was unfortunately not possible to obtain a record of these stray voltages.

8.4. As a matter of interest, the extraneous voltages induced on the telephone line due to traction currents were observed over a period of time and recorded (*Vide* Table III). The observations were made at the Mulund City Substation.

TABLE III

Section exposed to induction	Longitudinal voltage to earth on the trunk telephone line	Remarks
Vikhroli-Mulund Section ..	2 volts fluctuating ..	Train stationary at Mulund R. S.
	6 volts fluctuating ..	Train accelerating towards Bombay.
	1 volt fluctuating ..	Train stationary at Mulund R. S.
	2 volts fluctuating ..	Train accelerating towards Kalyan.
	1 volt fluctuating ..	Trains moving in opposite directions.
	1 to 1·5 volts fluctuating	Train accelerating towards Kalyan.
	1—5 volts fluctuating	Goods train accelerating towards Kalyan.
	3 volts fluctuating ..	Train accelerating towards Bombay.
Bombay-Mulund Section ..	1 volt fluctuating ..	No train visible.
	4 volts fluctuating ..	No train visible.
	9 volts fluctuating ..	Train accelerating towards Kalyan.
Bombay-Kalyan Section	1 volt fluctuating ..	No train visible.

PART III

DETERMINATION OF THE SCREENING EFFECT DUE TO EARTHED CONDUCTORS

9.1.1. The induction tests described in para 7.1.2. was repeated using one or more of the power conductors or telephone wires (other than those under test) as grounded screen wires. The terminals of the screen wires were solidly earthed for the purpose of introducing an earthed screen circuit. The results of these experiments are graphically indicated in Figs. 12 to 14, the relevant observations are included in the Appendix I. This test enables experimental evaluation of the screening factor of an earth return circuit because,

$$\text{Screening factor} = \frac{\text{Induced voltage with the earthed screen wires.}}{\text{Induced voltage without the earthed screen wires.}}$$

In this manner, the screening effect which results by using successively one power conductor, two power conductors, one communication conductor and two communication conductors as earthed screen wires was determined.

9.1.2. Theoretical methods have been developed for calculating approximately the screening influence of ground wires in the case of simple configurations :—

(*i*) Carson's formula (Report of the Joint Sub-Committee of Development and Research, *Edison Electric Institute and Bell Telephone System, Vol. IV P. 17*), and

(*ii*) Method adopted by Radley and Whitehead (JIEE Vol. 74, March 1934, p. 221). These formulae are given for reference in Appendix III.

9.1.3. For the parallelism situation in the Amritsar-Jullundur Section, the screening factors were calculated by both the above formulae for the various cases, and the results indicated reasonable agreement between the two methods. The calculated results are also comparable with the experimental figures to a remarkably close degree. The only unsatisfactory feature about this test was the fact that the induced voltages on the two limbs of the telephone pair CDP3 were unequal.

TABLE IV

Particulars	Test figures	CALCULATED FIGURES			
		As per method given in the Report of Joint Sub-committee of Development & Research		As per method given in JIEE Vol. 74, March, 1934	
		%	Volts	%	Volts
Unscreened Voltage	..	..	3·72*	..	3·72*
Screening factor due to ground wires on power line.	..	95	..	93.9	..
Voltage after allowing for screening due to ground wires on power line.	3·5	..	3·534	..	3·492
Screening factor due to one power conductor used as screen.	..	64·5	..	60·75	..
Voltage after allowing for screening due to one power conductor used as screen and ground wires on power line.	2·2	..	2·28	..	2·12
Screening factor due to two power conductors used as screen.	..	47·8	..	42·6	..
Voltage after allowing for screening due to two power conductors used as screen and ground wires on power line.	1·4	..	1·689	..	1·487
Screening factor due to one communication wire used as screen.	..	95·15	..	95	..
Voltage after allowing for screening due to one communication wire used as screen and ground wires on power line.	3·345	..	3·363	..	3·32
Screening factor due to two communication wires used as screen.	..	88·8	..	88·4	..
Voltage after allowing for screening due to two communication wires used as screen and ground wires on power line.	3·125	..	3·14	..	3·086

*Figures based on earth resistivity of 3000 ohms/cm³.

9.2. In the case of the Bombay tests, the chief factors, responsible for the screening influence are the steel ground wire on the power line and the railway tracks. Calculations were made of the unscreened induced voltage and of the screening factor due to the ground wire. The voltage arrived at after allowing for this screening was compared with the observed induced voltage, from which the screening effect of the railway tracks was evaluated. (*Vide* Fig. 8).

10. *Conclusions.*

10.1. Despite a few discrepancies here and there, the tests described above are considered satisfactory. It has been possible to obtain remarkably close agreement between the values of mutual coupling for earth return circuits as theoretically calculated and as actually measured. Similarly, satisfactory agreement between the calculated and measured values of shielding factors shows that it is possible to predict with a reasonable degree of accuracy in any given simple situation the extent of interference due to low frequency electromagnetic induction between a power and a proximate telephone line.

10.2. It is realised, however, that one of the uncertain factors entering into this problem is the earth resistivity. While the four electrode method using the earth testing megger gives a fair idea of the earth resistivity, and is found to be good enough for the evaluation of mutual coupling between two earth return circuits, it is felt that further investigations should be made to evolve methods of determining earth resistivity with increased accuracy.

It is proposed to pursue these investigations further, as opportunities arise.

सत्यमेव जयते

APPENDIX 1

ELECTROMAGNETIC LOW FREQUENCY INDUCTION TESTS CARRIED OUT AT AMRITSAR

On August 7th, 1949

(*a*) Preliminary checks on telecommunication lines CDP 3 and CDP 4.

	CDP 3	CDP 4
Insulation to earth	Beyond range	Beyond range
Cross insulation	Beyond range	Beyond range
Conduction on limb A	205 ohms.	205 omhs.
Conduction on limb B	205 ohms.	205 ohms.
Loop resistance	410 ohms.	410 ohms.
Localisation	*Nil*	*Nil*

Note.—Carrier lines CDP 3 and CDP 4 were in good working condition.

(*b*) Experiment 1 (Fig. 11)—No screening conductors.
Inducing line—Amritsar-Jullundur 132 kV line.
Induced line—CDP 3.

Case (*i*)—230 Volts Single phase 50 cycles per second supply between Red phase conductor and the earth.

Current in the inducing line in amperes	Voltage measured on the induced line	
	Limb A	Limb B
1·0	2·6	2·6
2·0	4·23	5·88
3·0	9·31	8·54
4·0	14·22	14·22

Case (*ii*)—230 Volts Single phase 50 cycles per second supply between the three phases of powerline bunched together and the earth.

Current in the inducing line in amperes	Voltage measured on the induced line	
	Limb A	Limb B
1·0	2·6	2·54
2·08	5·77	5·77
3·0	9·31	9·31
4·0	14·18	14·18
5·0	17·22	17·22
6·0	19·88	19·88
7·0	18·0	22·60

(*c*) Experiment 2 (Fig. 12)—Power conductors used as screen wires.

Inducing line—Amritsar-Jullundur 132 kV line.

Induced line—CDP 3.

Case (*i*) —230 Volts Single phase 50 cycles per second supply between Red phase conductor and earth ; and the Blue phase conductor earthed at the terminals.

Current in the inducing line in amperes	Voltage measured on the induced line	
	Limb A	Limb B
1·0	1·117	1·53
2·0	2·235	3·54
3·0	4·11	5·78
4·0	5·66	7·94
3·0	4·11	5·78
2·0	2·445	3·54
1·0	1·175	1·647

Case (*ii*)—230 Volts Single phase 50 cycles per second supply between the Red phase conductor and earth ; and the Blue and Yellow phase conductors earthed at the terminals.

Current in the inducing line in amperes	Voltage measured on the induced line	
	Limb A	Limb B
1·0	1·058	1·256
2·0	1·889	2·605
3·0	2·94	4·29
4·0	4·11	5·66
3·0	2·885	4·14
2·0	1·778	2·445
1·0	0·976	1·117

(*d*) Experiment 3 (Fig. 13)—Communication wires used as screen wires.

Inducing line—Amritsar-Jullundur 132 kV line.

Induced line—CDP 3.

Case (*i*)—230 Volts Single Phase 50 cycles per second supply between all the phase conductors and earth; and limb A of CDP 4 earthed at terminals.

Current in the inducing line in amperes	Voltage measured on the induced line	
	Limb A	Limb B
1·0	1·66	2·77
2·0	3·77	5·44
3·0	6·33	8·74
4·0	8·54	13·67
5·0	12·56	16·44
6·0	14·9	19·14
7·0		[illegible]

Case (ii)—230 Volts Single phase 50 cycles per second supply between all the phase conductors and earth ; and both the limbs A and B of CDP 4 earthed at the terminals.

Current in the inducing line in amperes	Voltage measured on the induced line	
	Limb A	Limb B *
1·0	1·66	1·44
2·0	3·88	5·33
3·0	6·56	8·74
4·0	8·74	13·32
5·0	13·0	16·22
6·0	15·1	18·93
7·0	18·0	22·7

* These observations are plotted under Fig. 14.

(e) Experiment 4 (Fig. 14)—Communication wires used as screen.

Inducing line—Amritsar-Jullundur 132 kV line.

Induced line—CDP 3.

Case (i)—230 Volts Single phase 50 cycles per second supply between all the phase conductors and earth ; and both the limbs A and B of CDP 4 earthed at the terminals as well as at Beas, an intermediate location.

Current in the inducing line in amprees	Voltage measured on the induced line	
	Limb A	Limb B
1·0	1·61	2·6
2·0	3·71	5·16
3·0	3·77	8·31
4·0	7·9	12·78
5·0	12·3	15·33
6·0	13·66	17·11
7·0	16·1	21·42
6·0	13·66	17·0
5·0	12·17	15·22
4·0	9·11	12·56
3·0	7·47	9·42
2·0	3·66	5·16
1·0	1·55	2·43

Case (*ii*)—230 Volts Single phase 50 cycles per second supply between all the phase conductors and earth; and both the limbs A & B of CDP 4 earthed at the terminals as well as at Beas and Kartarpur, two intermediate locations.

Current in the inducing line in amperes	Voltage measured on the induced line	
	Limb A	Limb B
1·0	1·66	2·6
2·0	3·65	5·11
3·0	5·88	8·1
4·0	7·79	12·67

(*f*) Experiment 5 (Fig. 15)—No screen wires.

Inducing line—Jogindernagar-Amritsar-Jullundur 132 kV lines.

Induced lines—CDP 3—between Amritsar and Jullundur.

230 Volts Single phase 50 cycles per second supply from Jogindernagar between all the three phase conductors in parallel and the earth.

Current in the inducing line in amperes	Voltage measured on the induced line	
	Limb A	Limb B
2·2	5·88	7·46
2·0	5·55	7·21
1·78	4·94	6·55

APPENDIX II

ELECTROMAGNETIC LOW FREQUENCY INDUCTION TESTS CARRIED OUT AT BOMBAY

On November 27, 1949

(a) Preliminary checks on telecommunication lines under test (BOMBAY-KALYAN trunks 833 & 834) taken at 7-00 a.m. on 27th November 1949.

	Limb A	Limb B
Conduction test	227 ohms	227 ohms
Insulation to Earth	3·3 megohms	3·3 megohms
Cross insulation (Insulation between A & B)	..	6·5 megohms
Station earth at Bombay	..	1 ohm.

(b) *Test No. 1*—

Inducing line—Mulund-Vikhroli 22 kV line.

Induced line—Bombay-Kalyan trunk telephone lines.

(*i*) Three power conductors paralleled and earthed at Vikhroli end ; 230 V Single phase 50 cycles per second supply injected between wires and earth at Mulund.

(*ii*) Bombay-Kalyan trunk earthed at Vikhroli Voltage to earth measured at Mulund.

Current in 22 kV line in amperes	Induced Voltage on telephone wires	
	Limb A	Limb B
51·60	..	18·0
51·60	..	17·2
52·00	17·8	..
51·20	17·6	..
47·40	16·5	..
39·00	13·6	
42·80	..	15·0
39·00	..	13·8

N.B.—Phase angle between inducing current and induced voltage was separately measured and found to be 72°. The angle was found to be independent of the magnitude of the current and the voltage.

(e) *Test No. 2*—

(i) 230 Volts Single phase 50 cycles per second supply between the middle conductor and earth at Mulund, the terminal at Vikhroli being earthed.

(ii) Bombay-Kalyan trunk earthed at Vikhroli; Voltage to earth measured at Mulund.

Current in 22 kV line in amperes	Induced voltage on telephone wires	
	Limb A	Limb B
25·60	9·0	..
23·40	8·0	..
31·50	10·4	..
31·80	..	11·1
19·00	..	6·8
29·30	10·2	..

(d) *Test No. 3*—

(i) 230 Volts Single phase 50 cycles per second supply between the middle conductor and earth at Mulund, the terminal at Vikhroli being earthed.

(ii) Bombay-Kalyan trunk earthed at Bombay; Voltage to earth measured at Mulund.

Current in 22 kV line in amperes	Induced voltage on telephone wires	
	Limb A	Limb B
31·80	12·0	..
31·20	12·0	..
31·40	..	11·8
31·20	..	11·8
23·10	..	2·6

(e) *Test No. 4*—

(i) 230 Volts Single phase 50 cycles per second supply between the middle conductor and earth at Mulund, the terminal at Vikhroli being earthed.

(ii) Bombay-Kalyan trunk earthed at Bombay and Kalyan, Voltmeter introduced in series at Mulund.

Current in 22 kV line in amperes	Induced voltage on telephone wires
31·20	3·2
31·40	2·4
31·40	1·4
21·00	1·05
22·40	1·3

APPENDIX III

Formulae for Self and Mutual Impedances and for Shield Factor for Multiple Conductor Ground-return Circuits

I. Method for calculating shield factor due to grounded circuits as given in the Report of the Joint Sub-Committee on Development and Research (Edison Electric Institute and Bell telephone system)

The formulae given by Carson (Bell syestem Technical Journal, October 1925) for the self and mutual mpedances of ground return circuits can be put in the following forms, (A) giving the self-impedance of an arth return circuit composed of n similar conductors connected in parallel, and (B) the mutual mpedance of two earth return circuits composed of groups of n conductors and m conductors respectively.

$$Z_{22} = \frac{r}{n} + 0\cdot 28\times 10^{-3}f + j0\cdot 882\times 10^{-3} f \log_{10} \frac{2160}{A_g\sqrt{\frac{f}{\rho}}} \tag{A}$$

$$Z_{12} = 0\cdot 28\times 10^{-3}f + j\,0\cdot 882\times 10^{-3} f \log_{10} \frac{2160}{D_g\sqrt{\frac{f}{p}}} \tag{B}$$

both in ohms per kilofoot, where

r=Effective resistance of a single shielding conductor—ohms per kilofoot.

f= Frequency—cycles per second.

ρ=Earth resistivity—meter-ohms.

A_g=Geometric mean radius of n paralleled shielding conductors—feet.

$$= \left[(pa)^n \, d_{12}^{\,2} \; d_{13}^{\,2} \ldots d_{1n}^{\,2} \, d_{23}^{\,2} \ldots d_{2n}^{\,2} \ldots d_{n-1,\,n}^{\,2} \right]^{1/n^2}. \tag{C}$$

D_g=Geometric mean distance between n (1, 2......n) shielding conductors and m ($a, b..m$) disturbing (or disturbed) conductors—feet.

$$= \left(d_{1a} \, d_{2a} \ldots d_{na} \, d_{1b} \ldots d_{nb} \ldots d_{nm} \right)^{\frac{1}{nm}} \tag{D}$$

a=Radius of single shielding conductor—feet.

p= Factor accounting for internal flux of single shielding conductor.

= ·78 for solid non-magnetic conductor.

Formulae (A) and (B) give self and mutual impedances to a sufficient accuracy for the requirements of actical shielding problems for all cases where $D_g\sqrt{\frac{f}{\rho}}$ or $A_g\sqrt{\frac{f}{\rho}}$ is less than 500. The rmula for the shield factor for a shielding conductor of length L, grounded at its ends (the total terminal sistances being R) located close to the disturbing (or disturbed) conductor with the disturbed (or sturbing) conductor a considerable distance away is—

$$\eta = \frac{R}{L} + Z_{22} - Z_{12}\ (\text{or}\ Z_{23}) \Big/ \frac{R}{L} + Z_{22} \tag{E}$$

where Z_{22}—self impedance of shielding Conductors.

Z_{12}—Mutual impedance between shielding and disturbing conductors.

Z_{23}—Mutual impedance between shielding and disturbed conductors.

η=Shield factor.

11. Method for calculating shield factor due to grounded circuits as developed in the JIEE Volume 74, March 1934.

The mutual induction, where an auxiliary conductor is in parallel with the earth, is less than that with a simple earth return, and can be obtained from the induction in the latter case by multiplying by a screening factor η given by

$$\eta=(Z_1-M_1)/(Z_1+Z) \qquad \text{(A)}$$

To a first approximation Z is the impedance of the earth path and is given approximately by

$$Z = \left[\pi^2 f + j\omega\left(1 + 2\log_e \frac{2}{\gamma K h}\right)\right] \times 10^{-4} \text{ ohms per km} \qquad \text{(B)}$$

where $K=2\pi\sqrt{f/\rho}$; $\gamma=1\cdot7811$; f=frequency; h= height of fault conductor in cm. $\omega=2\pi f$; and ρ =resistivity of earth in CGS units.

Self impedance of earth wire Z_1= $\left[R_1 + j\omega\left\{A_1 + 2\log_e\left(\frac{h_1}{r_1}\right)\right\}\right] \times 10^{-4}$ ohms per km (C)

where R_1= resistance of earth wire in absolute ohms per cm ; h_1=height of earth wire in cm ; r_1= radius of earth wire in cm ; and A_1=internal inductance (in absolute units per cm).

The value of A_1 depends on the stranding and the presence of steel core but it is normally about 0·5.

Also mutual impedance $M_1 = \left[2j\omega \log_e\left(\frac{h_1}{S_1}\right)\right] \times 10^{-4}$ ohms per km (D)

where S_1=distance between the earth wire and the fault conductor, or the centre of gravity of the phase conductors for zero-phase currents.

FIG. 1

TOPOGRAPHICAL MAP OF JOGINDERNAGAR-AMRITSAR-JULLUNDUR POWER SYSTEM.

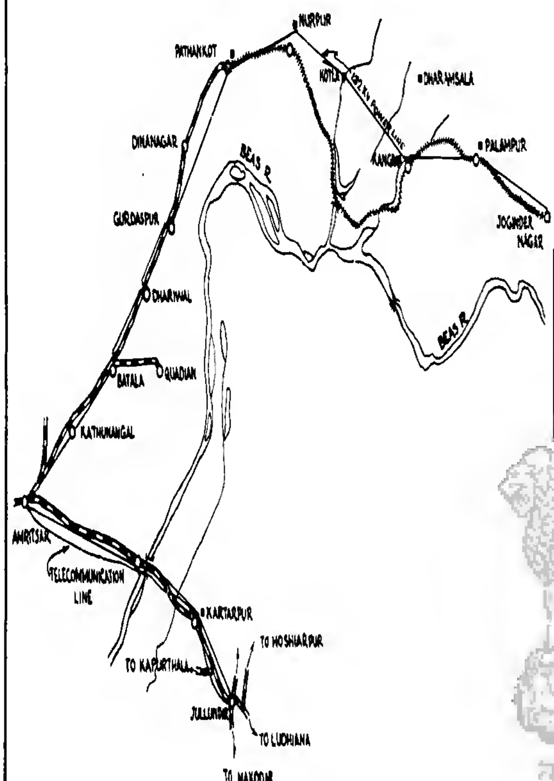


FIG. 2.

SCHEMATIC DIAGRAM OF 132 kV. LINES & S/S BETWEEN JOGINDER-NAGAR & JULLUNDUR.

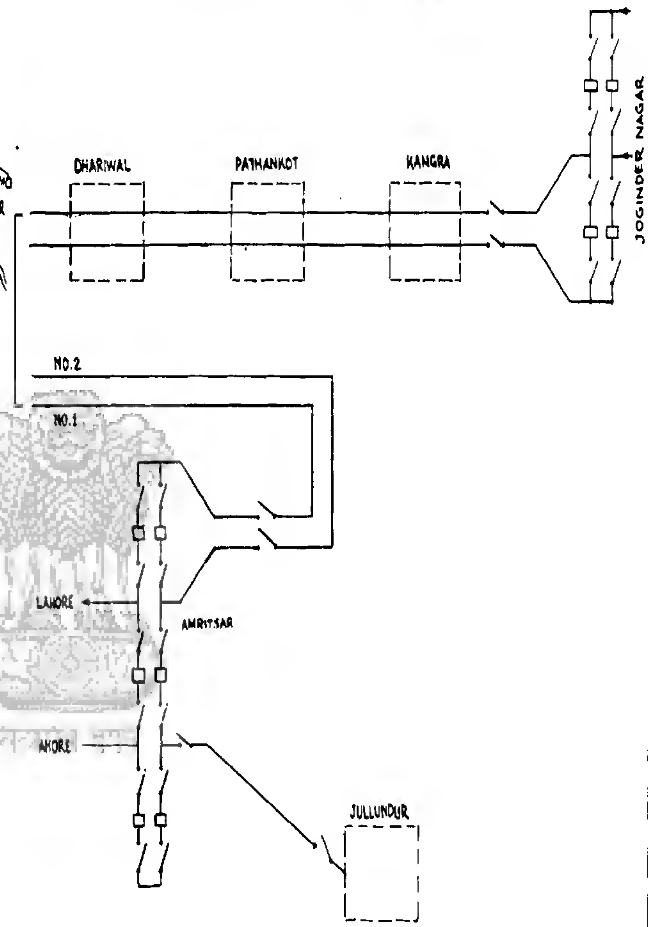
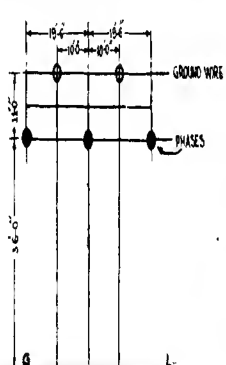


FIG. 3.

TOWER DIAGRAM FOR 132 kV. LINE BETWEEN AMRITSAR & JULLUNDUR



SIZES AND PROPERTIES OF CONDUCTORS.				
CONDUCTOR	STRANDING & DIAMETER		OVER ALL DIA. IN INCHES	RESISTANCE PER MILE
	ALUMINIUM	STEEL		
POWER CONDUCTORS	30/·102"	7/·102"	·714"	·2918 Ω
GROUND WIRE	-	7, 4	·33"	5·893 Ω

FIG.4

TOPOGRAPHICAL MAP OF 22kV. LINES OF S OF TATA POWER CO,
KALYAN-DHARAVI SECTION. ON.

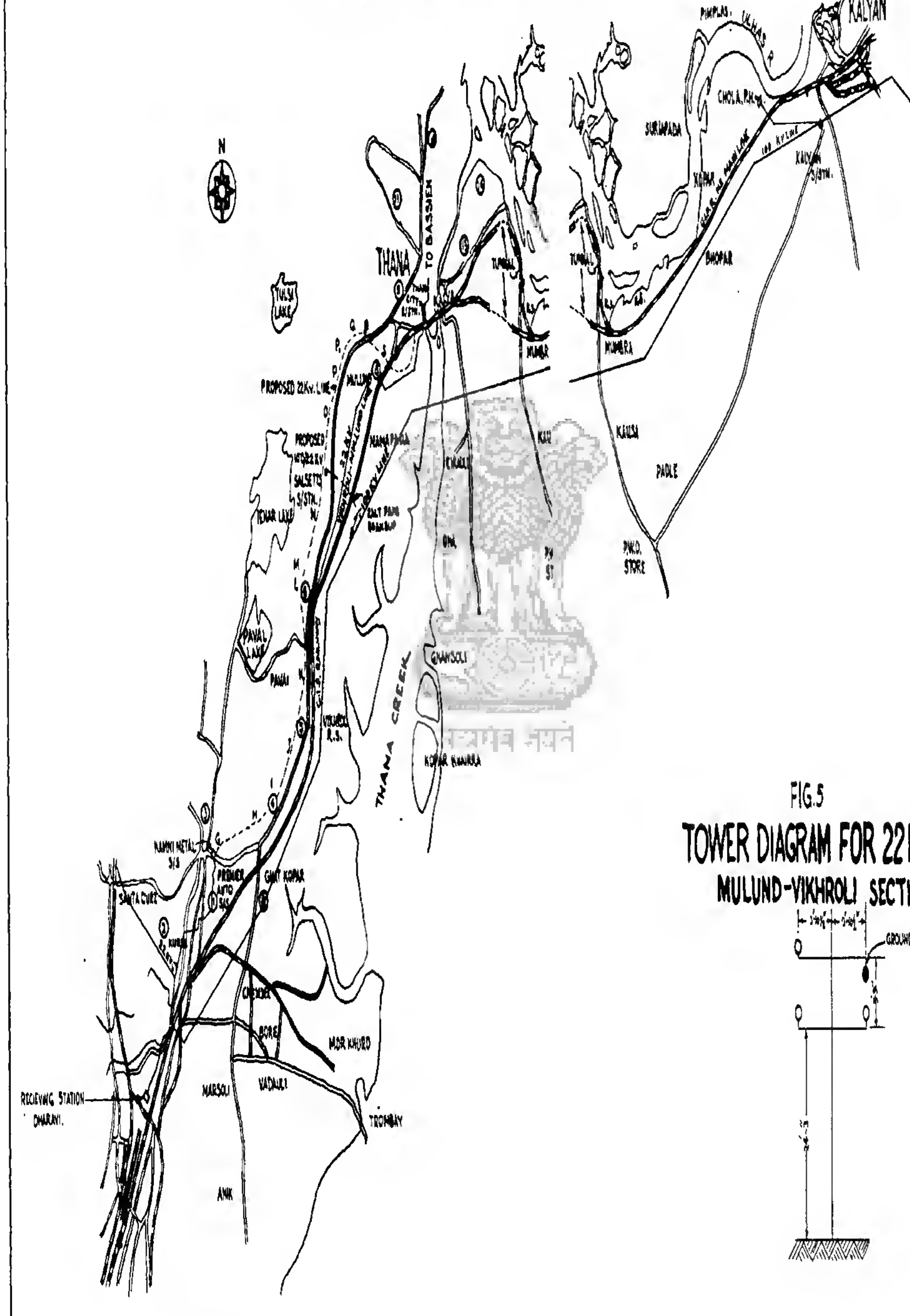


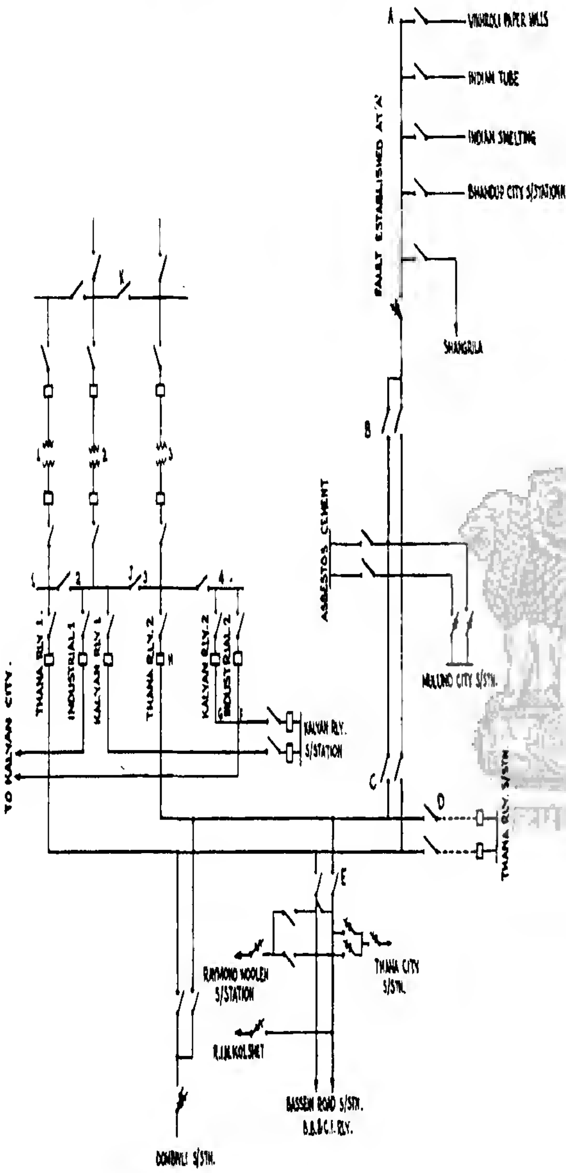
FIG.5

TOWER DIAGRAM FOR 22kV.LINE
MULUND-VIKHROLI SECTION

GROUND WIRE

FIG. 6.

SCHEMATIC DIAGRAM OF KALYAN - VIKHROLI 22 kV LINES & SUB-STATIONS.



SIZES AND PROPERTIES OF CONDUCTORS.				
CONDUCTOR	STRANDING & DIAMETER		OVERALL DIA. IN INCHES	RESISTANCE PER MILE
	COPPER	STEEL		
POWER CONDUCTORS	7/·131"	-	·393"	·51 Ω
GROUND WIRE	-	7/·128"	·384"	5·63 Ω

FIG NO. 7.

CONNECTIONS FOR EARTH RESISTIVITY TESTS

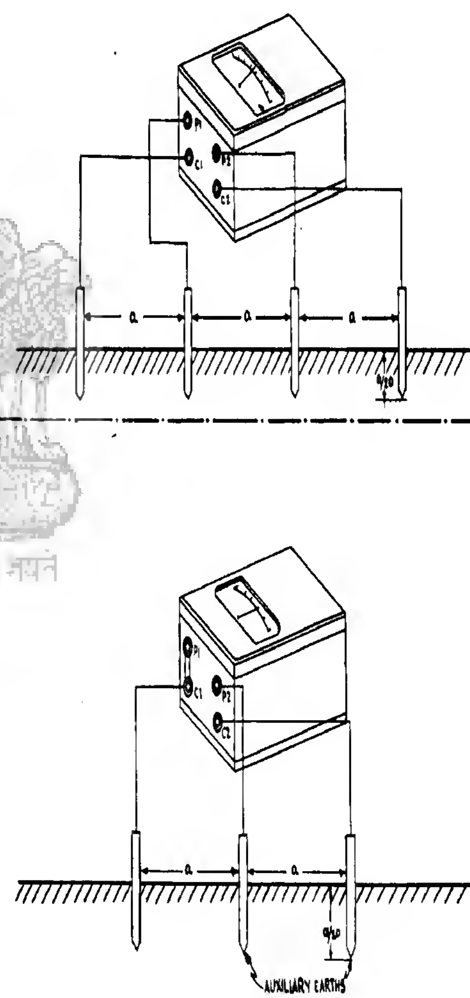


FIG.8

CURVE SHOWING THE OBSERVED VALUES OF VOLTAGE ON KALYAN-BOMBAY TRUNK LINES TO EARTH ON CIRCULATING CURRENTS BETWEEN POWER LINE AND EARTH IN MULUND-VIKHROLI SECTION.

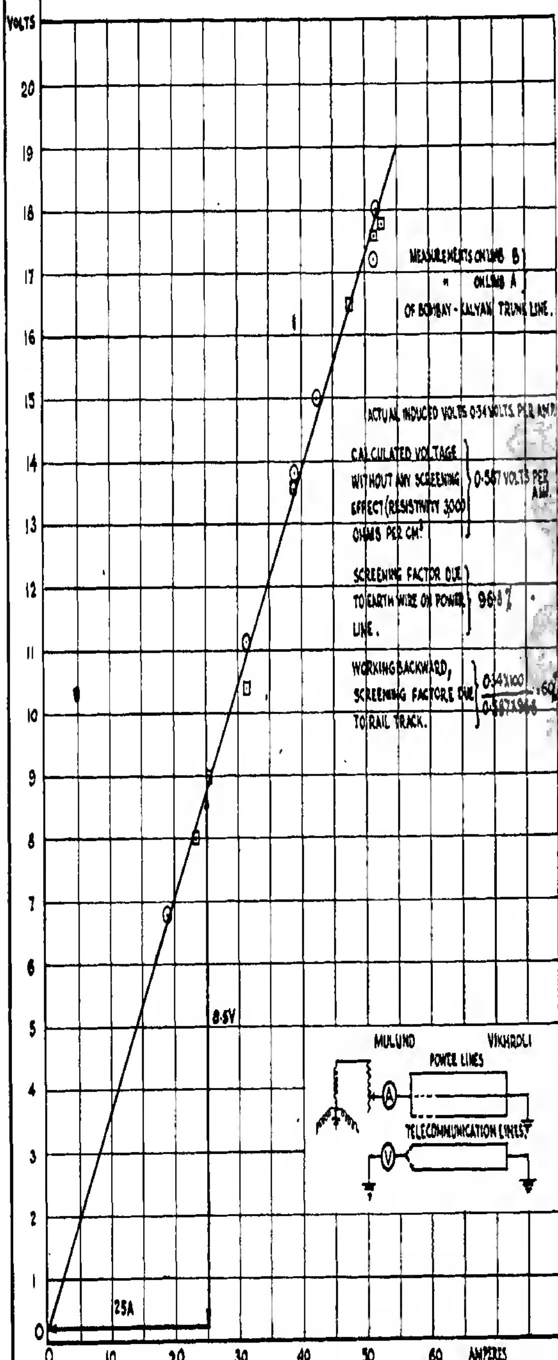
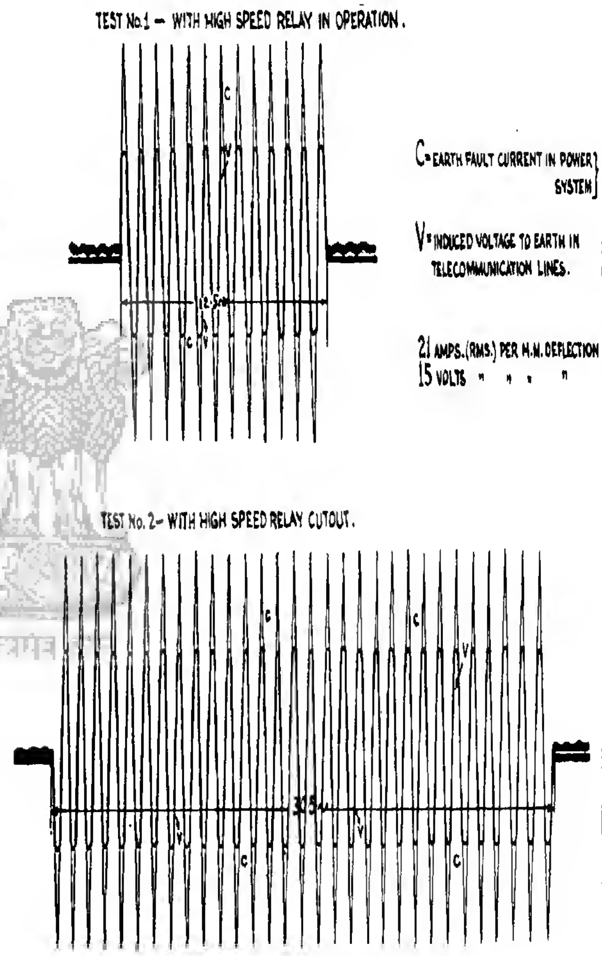


FIG.9 & 10

OSCILLOGRAPHIC RECORD OF SHORT CIRCUIT TEST CARRIED OUT ON 22kV. KALYAN-THANA-VIKHROLI LINE WITH A GROUND FAULT ESTABLISHED ON ONE OF THE CONDUCTORS AT VIKHROLI TO DETERMINE THE INDUCED VOLTAGE BETWEEN GROUND & GOVT. T.E.L. LINES PARALLELING 22kV. POWER LINE ON 27·11·49.



SHORT CIRCUIT CUR. = 460 AMPS. (RMS.) SYMMETRICAL

INDUCED VOLTAGE BETW TEL.LINE & GROUND. = 156 VOLTS " "

INDUCTIVE EXPOSURE IN AMRITSAR– JULLUNDUR SECTION – RESULT OF TESTS CARRIED OUT ON 7-8-1949

POWER LINE-132 KV LINE (S.C) AMRITSAR - JULLUNDUR — TELECOMMUNICATION LINE DELHI-AMRITSAR CARRIER LINE C.D.P3 IN THE AMRITSAR-JULLUNDUR SECTION

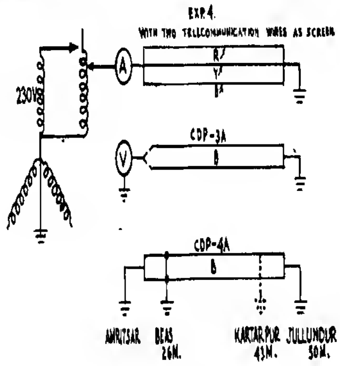


FIG.14

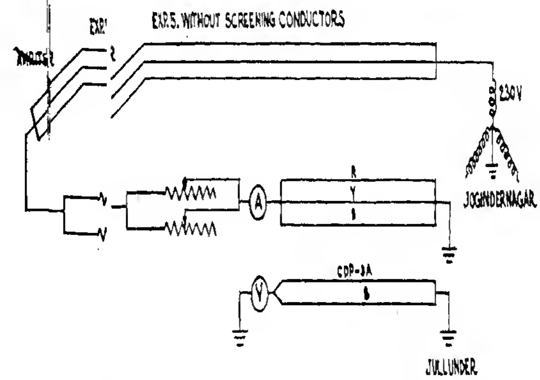
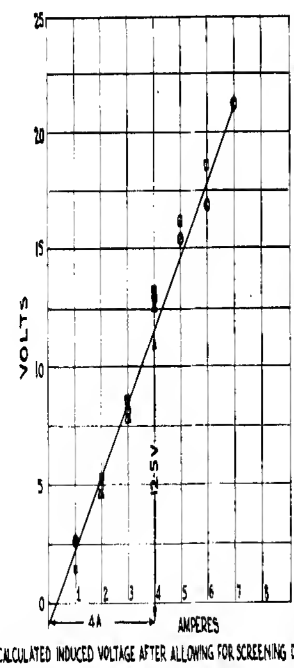


FIG.15.



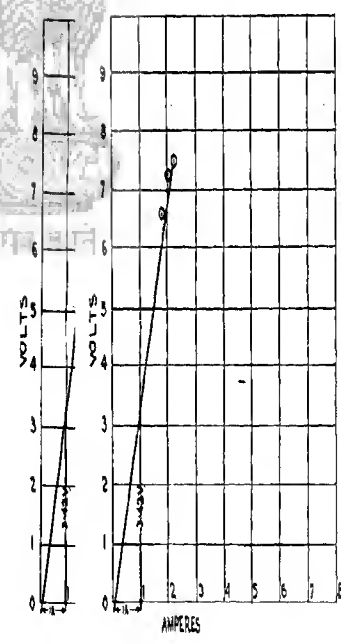
● EARTH AT ENDS.
⊙ EXTRA EARTH AT BEAS.
▲ " " " " & KARTARPUR

ACTUAL INDUCED VOLTAGE
$= \frac{12.5}{4} = 3.125$ VOLTS/AMP.

CALCULATED INDUCED VOLTAGE AFTER ALLOWING FOR SCREENING DUE TO GROUND WIRES ON POWER LINES – 3·534 VOLTS/AMP.

CALCULATED SCREENING FACTOR DUE TO TWO COMMUNICATION WIRES – 88%

CALCULATED INDUCED VOLTAGE – 3·14 VOLTS/AMP.



INDUCED VOLTAGE – $\frac{3.42}{1}$, 3.42 VOLTS/AMP.

NOTE:– SINCE IT WAS NOT POSSIBLE TO GET MORE READINGS THE ABOVE VALUE IS PROBABLY APPROX., BUT INDICATES THAT IT IS NOT VERY DIFFERENT FROM THE VALUE SHOWN IN FIG.11.

INDUCTIVE EXPOSURE IN AMRITSAR– JULLUNDUR SECTI N – R N – RESULT OF TESTS CARRIED OUT ON 7-8-1949

POWER LINE-132 KV LINE (S.C) AMRITSAR – JULLUNDUR – TELECOMMUNICATION LINE DELHI–AM DELHI–AMRITSAR CARRIER LINE C.D.P.3 IN THE AMRITSAR–JULLUNDUR SECTION

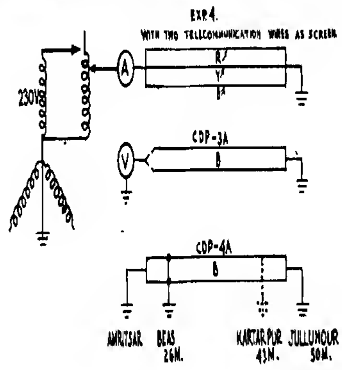


FIG.14

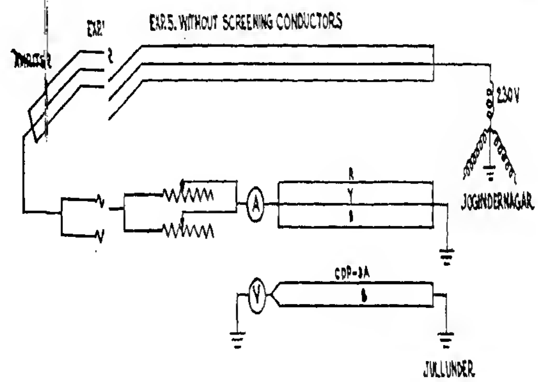
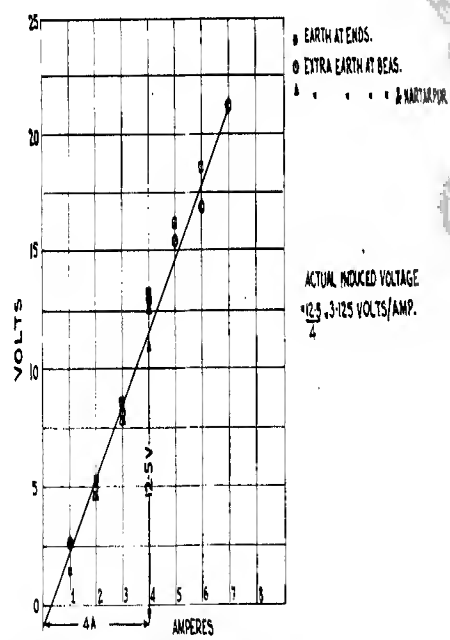
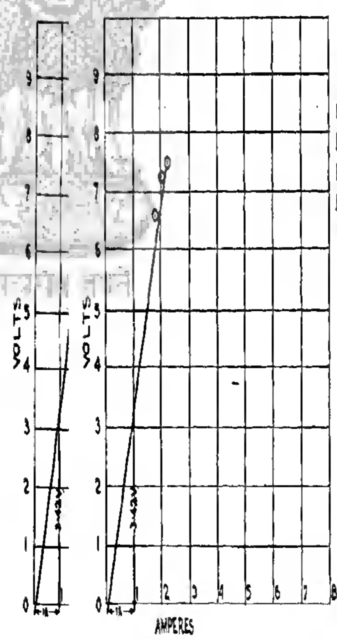


FIG.15.





INDUCED VOLTAGE – 3.42/1 = 3.42 VOLTS/AMP.

NOTE:– SINCE IT WAS NOT POSSIBLE TO GET MORE READINGS THE ABOVE VALUE IS PROBABLY APPROX., BUT INDICATES THAT IT IS NOT VERY DIFFERENT FROM THE VALUE SHOWN IN FIG.11.

CALCULATED INDUCED VOLTAGE AFTER ALLOWING FOR SCREENING DUE TO GROUND WIRES ON POWER LINES – 3.534 VOLTS/AMP.

CALCULATED SCREENING FACTOR DUE TO TWO COMMUNICATION WIRES – 88%

CALCULATED INDUCED VOLTAGE – 3.14 VOLTS/AMP.